

CHAPTER 2

BASIC METHODS AND CONCEPTS FOR MITIGATION ASSESSMENT

2.1 PREPARING FOR A MITIGATION ASSESSMENT

Key factors that need to be considered in preparing a mitigation assessment are discussed below:

- **Defining the Time Frame of the Assessment.** A mitigation assessment typically focuses on long-run opportunities for reducing GHG emissions or enhancing carbon sinks since it takes time for changes that could affect GHG emissions in a significant way to be adopted. In addition to a long-run focus, a country might also evaluate near-term policy and program options.
- **Defining the Scope of the Assessment.** A mitigation assessment may include a variety of areas. These include energy demand and supply, forestry, agriculture, rangelands, and waste management. Ideally, an assessment should include analysis of the impact of mitigation options (particularly in the energy sector) on the macro-economy. Countries should structure their assessment to address the topics of most importance, taking into consideration the resources available to perform the study. A mitigation assessment should include some consideration of policies and programs that can encourage adoption of mitigation technologies and practices. More detailed evaluation of particular policy/program options could follow an initial assessment.

Defining Primary Users of the Assessment. Countries should design their assessments to satisfy the needs of the various possible users or stakeholders. The primary users of the assessment are likely to be policy decision-makers who are responsible for evaluating and designing mitigation policies. The country's scientific community is likely to benefit from participation in the assessment process, and also from the compilation of data and access to new models, which will also be useful for other types of analysis. Other potential in-country users include the NGO community. In addition, the output of each assessment may be shared with interested groups in other countries, and regional and international organizations.

- **Defining Results that Meet the Users' Needs.** Defining the type of output desired from an assessment will help in selecting the areas where efforts should be focused. The output of a typical assessment will consist of economic, GHG, local environmental, and social impacts of mitigation options. It could also include a discussion of barriers to implementation of mitigation options and description of policies to overcome them. The importance to be placed on characterizing each type of output should be determined in consultation with the potential users of the assessment. Each team should also consider how best to present the results (e.g., journal articles, reports, briefings, workshops).
- **Selecting Approaches that are Consistent with Data Availability and Expertise of Researchers.** The sophistication of the analytical methods that will be used in the assessment will depend, in part, on the desired level of output detail. If approximate estimates of scenarios are sufficient, then detailed costing models may not be necessary.

The level of detail will determine the type and extent of data that need to be collected for the assessment. Often it may be difficult to collect new data through surveys or detailed technology characterizations. However, every attempt should be made to collate existing data, which often tend to lie unused. Alternatively, data may be collected through informal surveys, e.g., of technology manufacturers and energy users.

2.2 THE STRUCTURE OF A MITIGATION ASSESSMENT

The structure of a mitigation assessment will vary depending upon its goals and scope. The type of institutions involved in the study may also affect the structure. Studies in specific sectors such as energy or forestry can be conducted somewhat independently, yet it is important for all members of the study team to use common assumptions regarding basic parameters such as population and economic growth.

Although most of the work will be independent, interaction among the sector specialists can be beneficial. For example, the forestry specialists can provide the energy specialists with information on biomass resources that may be available for energy consumption in the future while the energy specialists can give the forestry experts information on the future demand for fuelwood. In addition, it is necessary for the analysts in sectors such as forestry, agriculture, and rangelands to work together to develop scenarios of how available lands may be utilized in the future.

The nature of a mitigation assessment will vary among sectors, but it is possible to describe a basic structure that illustrates the key components of an assessment and how they relate to each other (Figure 2-1). The first step is to assemble data for the base year on the activities and technologies/practices that are associated with GHG emissions or carbon storage. The type of data and the framework in which they are organized will obviously vary among sectors. In each case, however, the assembly of base-year data should draw on and be consistent with the GHG emissions inventory.

Once the base year has been documented in some detail, the remainder of the assessment involves an evaluation of what might or could occur in the future. The development of scenarios of the future requires data on the activities that result in GHG emissions or shape opportunities for carbon storage. The types of data include production of key industrial products, the number of urban and rural households in the residential sector, the number of vehicles in transportation, and demand for land and forest products. Development of scenarios requires a projection of the future levels of each kind of activity. Such projections in turn draw on assumptions made about growth in population, GDP, and other macro variables.

For each type of activity or resource demand, there are generally a number of technologies or practices that can be employed, each having different implications for resource use and GHG emissions or carbon storage. Because the range of technologies and practices that could reduce GHG emissions or sequester carbon is large, it is helpful to conduct a screening of potential technology options to select those that will receive further analysis. Examples of criteria that may be used for screening are presented in Section 2.4.

Once options have been selected for inclusion in the assessment, it is necessary to characterize technologies and practices with respect to their costs and other features (e.g., performance, lifetime, environmental characteristics, labor and infrastructure requirements). The technologies or practices may include those that are already available or in use, as well as those that are expected to be available in the future.

The information on future activity levels and potential technologies/practices is used to define scenarios that describe future resource use or production under a certain set of conditions. Scenarios should also take into account current and likely policies that are of importance in each sector. These include policies affecting pricing of energy and other resources, land use, transport infrastructure, as well as general economic policies that influence diffusion of new technologies (such as policies affecting domestic competition and foreign investment). The methods used to construct scenarios range from simple approaches that require the analyst to make numerous judgements and "mechanically" assemble a scenario, to complex models that take the input data and select specific technologies and their penetration rates based on various criteria (e.g., optimization of system costs).

Figure 2-1 here
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A mitigation assessment should include at least two scenarios for each sector considered. A "baseline" or "reference" scenario is a description of a plausible future in which no specific policy actions are taken to encourage actions that reduce GHG emissions or enhance carbon sinks. A "mitigation scenario" describes a future that is essentially similar to that in the baseline scenario with respect to overall economic and social trends, except that it assumes that policies or programs are implemented that encourage adoption of measures that will reduce GHG emissions or enhance carbon sinks (see Section 2.6 for further discussion of scenarios).

In analyzing the merits of mitigation options, standard techniques of benefit-cost analysis may be applied, with some modification (see Section 2.7). However, some of the impacts of a mitigation option may be difficult to express in monetary terms or even to quantify. Thus, cost-benefit analysis should be supplemented with quantitative and qualitative assessment of other criteria such as complementary environmental effects (e.g., reduction in local air pollution), secondary economic effects (e.g., employment creation), and social and political considerations (e.g., the impact on societal equity).

The combination of cost-benefit analysis and assessment of other criteria can be used to compare or rank mitigation options, which can support the definition of mitigation scenarios. A mitigation scenario may reflect only the technical potential of various options to reduce GHG emissions or to store carbon; or the analyst can estimate that part of the technical potential that may be achievable. Estimating the magnitude of GHG emission reduction or carbon storage that may be achievable within a given time frame requires identification and assessment of policies or programs that could be used to encourage adoption of mitigation options in each sector. A detailed evaluation of policies or programs may go beyond the scope of an initial mitigation assessment, however.

The scenarios provide estimates of the economic and other impacts within the sector being studied (e.g., investment requirements). It is important to also assess the impact of sectoral mitigation options (or of cross-sectoral options such as a carbon tax) on the overall economy, social goals, and the local environment. Various models may be used to analyze the interaction between the energy sector and the economy. Similar models have not been used to assess the impact on the economy of mitigation options in non-energy sectors, but models used for general analysis of agriculture and forestry could be modified for analysis of macroeconomic impacts of mitigation options in those sectors. In addition, methods that facilitate combined quantitative and qualitative assessment of multiple criteria may be used.

Once the full range of impacts of various mitigation options have been evaluated, the next step involves an assessment of policy and program options to encourage their adoption. This assessment may go beyond the rough assessment used to define mitigation scenarios. It might combine quantitative analysis with workshops that facilitate interaction between the analysts and relevant policy-makers, and other interested parties in a particular country. The goal of such interaction could be the development of a national GHG mitigation strategy for the sector.

The structure described above generally applies for the energy sector and the non-energy sectors. However, the analysis of the energy sector is complicated by the fact that it requires an integration of energy demand and supply in order to estimate the GHG impacts of mitigation options in the energy demand sectors, and to compare demand-side and supply-side options. It also tends to be larger in scope, since the use of energy pervades the entire economy.

2.3 TIME HORIZON IN MITIGATION ASSESSMENT¹

The time horizon of the analysis plays a critical role in planning a mitigation assessment and selecting methods. For discussion purposes, it is useful to define time periods somewhat arbitrarily as near-term (1-5 years), mid-term (15 years), and long-term (15-50+ years).

A classic definition of the near term is that period of time during which the capital stock is fixed, while the technology mix and allocation of input factors across producing sectors is variable in the long term. Since the economy's structure and productive capacity are fixed in the short run, price changes are generated by fluctuations in variables reflecting seasonal cycles or transient impacts such as severe weather, oil spills, geopolitical conflicts, labor strikes, and so forth.

Extending the forecast horizon shifts the emphasis towards market clearing and relatively stable trends in variables. While the mid-term time frame extends far enough for innovations to occur in some sectors, the general characteristics of available technology, the capital stock of energy-consuming equipment, and demographic patterns can be anticipated with reasonable confidence. Although new technologies are continually emerging and their eventual market penetration is uncertain, gradual capital stock turnover implies that most of the capital equipment that will be used during the mid-term period is already in place, available on the market, or on the verge of commercialization.

Long-term modeling focuses on paths of key variables such as demographic patterns, cumulative impacts such as the depletion of nonrenewable resources, and changes in structural relationships between exogenous and endogenous variables due to capital stock turnover, the penetration of new technologies, emergence of alternative energy sources, and interindustry shifts in the composition of demand.

In the short term, only minor changes to the energy system can be anticipated to take place. Even in a mid-term perspective, substantial deviations from the existing planned energy system are limited due to long lag times for construction of supply facilities, and similar considerations apply for technology innovations in other sectors. Hence, the usefulness of advanced integrated models is less if one is addressing short-term impacts only. In this case, careful study of recent trends and evaluation of existing plans (expansion of the supply side is usually planned for the next decade) and available retrofit options, together with use of simple sector-specific models, is sufficient.

However, in GHG mitigation the real challenge is to be able to sustain reduced emission levels (or lower them further) in a long-term perspective. The goal of identifying opportunities for GHG mitigation that can have a significant impact in the future calls for long-term modeling of the energy and non-energy sectors. In the presentation of models in this book, we concentrate on models suited for addressing long-term development of the energy and non-energy sectors.

2.4 APPROACHES FOR ANALYSIS OF MITIGATION OPTIONS

Developing a national mitigation strategy requires identification and analysis of different actions that government could take to encourage adoption of technologies and practices that reduce GHG emissions or enhance carbon sinks. Based on the analysis, policy-makers can then decide which options not only satisfy specific policy objectives but are also within institutional, political, and budget constraints. Typically,

¹ This section draws on Kydes *et al.* (1995).

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the analytic process will follow a series of steps, each of which produces information for decision-makers. The manner in which these steps are performed will reflect each country's resources, objectives, and decision-making process.

Two general approaches have been used for mitigation assessment. The top-down method assumes a macroeconomic perspective wherein mitigation costs are defined in terms of losses in economic output, income, or GDP. A key assumption underlying many top-down analyses is that the baseline scenario represents the economy in equilibrium, with all factors of production employed efficiently given prevailing prices. The bottom-up approach focuses on individual processes such as end-use energy consumption, production of specific crops, and specific forest management schemes. For each relevant process, the approach attempts to estimate the costs associated with changes that result in GHG emission reductions or other impacts.

The fundamental difference between the two approaches is in the perspective taken by each on consumer behavior. The top-down approach assumes that consumers always act to maximize their utility or profit. According to this approach, if energy efficiency is less than it could be, it is because consumers see no economic gain in becoming more efficient. In contrast, the bottom-up approach assumes that various market barriers prevent consumers from taking actions that otherwise would be in their or the national economic self-interest. These market barriers could include lack of information about energy efficiency opportunities, lack of access to capital to finance the efficiency investment, and separation of responsibilities for making capital investments and paying operating costs (Lohani and Azimi, 1992).

In general, an assessment carried out using the bottom-up approach will very likely show significantly lower costs for meeting a given mitigation objective than will one using a top-down approach. To some extent, the differences may lie in a failure of bottom-up studies to accurately account for all costs associated with implementing specific actions. Top-down methods, on the other hand, can fail to account realistically for consumer and producer behavior by relying too heavily on aggregate data (Krause *et al.*, 1993). In addition, some top-down methods sacrifice sectoral and technology detail in return for being able to solve for general equilibrium resource allocations. Finally, top-down methods often ignore the fact that economies depart significantly from the stylized equilibria represented by the methods (Boero *et al.*, 1991). Each approach, however, captures costs or details on technologies, consumer behavior, or impacts that the other does not. Consequently, a comprehensive assessment should combine elements of each approach to ensure that most relevant costs and impacts are accounted for.

2.4.1 Tools for Mitigation Assessment

A variety of models and methods can assist the analysis of mitigation options. The primary ones described in this book are listed in Table 2-1. These range from bottom-up accounting models for the energy or forestry sector to top-down models of the whole economy in which energy or forestry are but one sector. For the energy sector, the models include accounting frameworks (LEAP and STAIR), optimization models (MARKAL and ETO), and an iterative equilibrium model (ENPEP). Each of these models may be used for integrated assessment of energy demand and supply although the approach and method varies among them. In addition to these quantitative models, a decision framework process (AHP) may be used for combined quantitative and qualitative evaluation of alternative technology options. These models are described in Chapter 3. Considerations for selecting among the different energy sector models are also presented in Chapter 3.

In industrialized countries, several top-down models have been developed for mitigation assessment, primarily to analyze the impact of carbon taxes. Similar models have not been widely applied to analyze changes in taxes, investment, or energy flows of developing and transition countries. Two top-down models that have been developed primarily for the developing countries are the MIMEC and LBL-

CGE models. In addition, a recently developed hybrid model (MARKAL-MACRO) merges the bottom-up and top-down approaches.

In the non-energy sectors, bottom-up analytical methods have largely focused on the estimation of carbon and other GHG flows. The COPATH model has been used for carbon accounting and scenarios in the forestry sector, while COMAP has been developed for estimating the impacts of mitigation options in the forestry sector. EPIC and CENTURY are plant/soil simulation models which may be used to simulate carbon cycling dynamics in agricultural and rangeland ecosystems. For assessment of methane mitigation options in agriculture and waste management, simple spreadsheet models are available.

Top-down models have not been used in the non-energy sector for the assessment of GHG-related impacts in the developing and transition countries. Countries where agriculture or forest products form a significant share of the monetized economy have models or methods that can analyze the GDP impact of changes in domestic or international prices of these products. Many countries, for example, have used computable general equilibrium (CGE) models for analyzing the impacts on GDP, income distribution, and rural employment. These models may be modified for the purpose of a top-down analysis of the impacts of GHG mitigation options. The LBL-CGE model could also be modified for this purpose.

Table 2-1.
Examples of Analytical Tools Available for Mitigation Assessments

Topic	Analytical Tools
Energy Sector Accounting Models Optimization Models Iterative Equilibrium Model Decision Analysis Framework	LEAP, STAIR MARKAL, ETO ENPEP Analytical Hierarchy Process (AHP)
Non-Energy Sectors Forestry Agriculture Rangelands Waste Management	COPATH, COMAP EPIC, CENTURY CENTURY Landfill Gas Model
Energy-Economy Interaction	LBL-CGE, MARKAL-MACRO

2.5 SCREENING MITIGATION OPTIONS

The nature and importance of the screening process varies depending on the modeling approach. For each sector being studied, one approach is to develop a list of mitigation options that may be of interest. Various criteria, such as those listed in Table 2-2, are important for both screening and in-depth analysis of mitigation options. At the screening stage, one makes a rough assessment of the potential attractiveness of options, while the goal of the analysis is to quantify or carefully identify various impacts.

A useful approach for screening options is to prepare a matrix as shown in Table 2-2 for each sector. The matrix provides a qualitative indication of the attractiveness of each option by ranking it high, medium, or low, as judged according to each criterion. This matrix should be completed prior to conducting sectoral analyses in order to identify the options to be evaluated in depth.

Screening out the non-promising options requires careful judgement. An obvious reason for screening out options is if its wide-scale application is not viable. For example, location of options in environmentally or otherwise sensitive areas may rule them out for political reasons. The relationship between a mitigation option and development goals is important to consider. In addition, there may be options, such as reducing traffic congestion, which may be difficult to analyze since quantifying the impact on GHG emissions may be difficult to do. However, if the option is important for non-GHG reasons (e.g., as a measure to reduce urban air pollution), then simple assumptions may be made to roughly estimate its GHG impact.

Screening of options may require consideration of likely future conditions. For example, electricity-saving options may have a very small impact on GHG emissions if much of the electricity is hydro-generated. However, if the mix of generation is likely to shift toward more thermal generation, then electricity-efficiency options could become important.

2.6 DEFINING SCENARIOS

What will happen in the future cannot be predicted, but it is possible to develop scenarios of the future that reflect the consequences of different, but plausible, economic and technological conditions. For the purpose of mitigation analysis, at least two different scenarios are necessary. One scenario should reflect a baseline case, while the other should reflect the impact of mitigation options.

- **Baseline Scenario.** As mentioned earlier, a baseline scenario should represent a future in which there are no policies or programs designed to encourage or require actions that reduce GHG emissions or enhance carbon sinks. Defining a reasonable baseline scenario is a critical element in a mitigation assessment since the incremental costs and benefits of mitigation options will depend on the definition of the baseline scenario.

A baseline scenario should not simply extrapolate from recent and current trends but rather incorporate a judgement of the likely evolution of resource-consuming and producing activities and technologies. This type of scenario is sometimes called "business-as-usual." Such a scenario would include some degree of adoption of technologies or practices that improve the efficiency of resource use and thereby reduce GHG emissions. In transition countries in particular, a baseline scenario will be quite different from historical trends.

In both developing and transitional countries, where considerable economic and social change is expected over a period of the next several decades, it can be quite difficult to select a single image of the future as more likely than another. A study team might choose to define more than one baseline scenario. For example, alternate scenarios could reflect low, medium, and high economic growth. Obviously, there is a trade-off between keeping the assessment manageable and defining numerous baseline scenarios.

If sectors of the economy contain structural inefficiencies (such as subsidized prices), it is important to be able to separate the costs and benefits of removing these inefficiencies from the impacts directly attributable to GHG mitigation measures. This ability to distinguish between general structural impacts and the impacts of mitigation policies is

important regardless of whether an explicit policy of structural reform is assumed in the baseline scenarios.

Table 2-2. Criteria for Screening of Mitigation Options

Criteria	Mitigation Option 1	Mitigation Option 2	Mitigation Option n
Potential for large impact on CO ₂ or other GHGs	High	Low	Medium
Direct cost/benefit ratio of the option	Low	High	High
Indirect economic impacts <ul style="list-style-type: none"> - Increase in domestic employment - Decrease in import payments 	Medium Low	Low Medium	Low Uncertain
Consistency with national environmental goals <ul style="list-style-type: none"> - Reducing emissions of air pollutants - Effectiveness in limiting other environmental impacts 	Low Medium	High Low	Medium Low
Potential ease of implementation	Low	Medium	High
Long-term sustainability of option	High	Uncertain	Medium
Consistency with national development goals	High	Low	Medium
Data availability for evaluation <ul style="list-style-type: none"> - Technology characterization - Costs of implementation programs 	Low High	Uncertain Low	High Uncertain
Other sector-specific criteria	Low	High	Uncertain

Note: Numerical rankings may also be used.

- **Mitigation Scenario.** A mitigation scenario reflects a future in which climate-change mitigation is a primary motivation for adoption of technologies and practices that reduce GHG emissions or enhance carbon sinks. It may reflect only the technical potential for reducing GHG emissions or storing carbon, or it may incorporate estimates of what is achievable considering the many factors (institutional, cultural, legal, etc.) that may limit the implementability of the technically available options. Ideally, both the technical and the achievable potential should be reported.

A study team could define and develop several mitigation scenarios. For example, alternate mitigation scenarios could reflect different degrees of emissions reduction or carbon storage relative to the baseline (e.g., 10%, 20%, 30%). A study team might also want to define mitigation scenarios that highlight particular types of technologies (e.g., renewable energy technologies).

For both the energy and non-energy sectors, scenarios developed using a bottom-up approach take into consideration end-users' needs for energy, forest products, and land. By explicitly taking these needs into account, end-use scenarios are less likely to over- or understate final demand for products.

2.6.1 Setting Basic Parameters

In constructing scenarios, certain underlying parameters must be specified and treated consistently. Assumptions should be consistent with those used in GHG inventories and vulnerability and adaptation studies.

- **Selecting the Time Frame for the Assessment.** The time frame for GHG scenarios is often quite long, extending from 50 to 100 years. For mitigation options analysis, however, it is usually better to consider shorter time frames since the projection of macro-economic variables and the characterization of technologies beyond 20-30 years become quite uncertain. Analysts have generally used the period up to 2020 or 2030 as a relevant time frame to analyze the economics of mitigation options. For the forestry sector, long-rotation tree plantations may need to be evaluated over a longer time frame. Projections of emissions in the near-term (e.g., 2000) may also be helpful in evaluating policy options. Analysis may be conducted for either a single end year or several forecast years. In a dynamic framework, each consecutive time period is linked to the other over the entire time horizon.
- **Socio-Economic Variables.** Projections of socio-economic variables such as economic and population growth rates, land-use patterns, economic structure, and urban-rural population proportions may be obtained from national planning ministries in each country. Most countries have multi-year plans that show both economic structure and population growth assumptions. If these are not readily available, World Bank or UN projections of population and economic growth may be used instead. Economic growth projections are usually for a relatively short time period (5-10 years), and these should be extrapolated as realistically as possible for subsequent periods.
- **Land-use and Natural Resource Considerations.** Changes in land-use patterns will have an important bearing on GHG emissions from forestry, agriculture, and drylands, and they will also affect the vulnerability of the country to climate change. It is therefore important for both mitigation and vulnerability assessment staff to assess the current patterns of land use and their evolution over time. Changing the evolution of land-use

patterns requires strong government policies and programs. Consideration should be made as to whether these types of policies are likely to occur as a mitigation option in each country. If only technical options are to be evaluated, then each "likely trends" scenario of land-use change should be used to evaluate both baseline and mitigation scenarios. If strong policies to modify evolving land-use patterns are plausible, then the mitigation scenario should consider a land-use pattern different from the one used for the baseline.

2.7 COST-BENEFIT ANALYSIS OF MITIGATION OPTIONS

A key objective of a mitigation assessment is to identify those options that maximize economic benefits or minimize the economic costs of restraining GHG emissions growth. Cost-benefit analysis has traditionally been used for project evaluation, but it has also been applied to mitigation assessment to estimate and compare relevant costs and benefits in a consistent and comprehensive manner. Cost-benefit analysis suggests that mitigation options that produce the greatest net benefit be selected among competing options. Strict application of this rule to the evaluation of mitigation options is not possible, however, since the benefits of mitigation options with regard to climate change cannot be monetized with any certainty at this point in time and are likely to vary among regions.

The monetizable portion of the costs and non-GHG benefits may be stated in money terms. Since the carbon GHG benefits cannot be easily monetized, the benefits may be stated simply in terms of either tonnes of carbon abatement or storage, or for non-carbon GHGs, in terms of carbon-equivalent.

Cost-benefit analysis should be supplemented by assessment of non-monetizable costs and benefits other than GHG abatement. These might include reduced emissions of other pollutants or an improvement in biodiversity. These costs and benefits should be quantified or at least described so that decision-makers can take them into account. Similarly, the impacts of an option on different societal groups may also need to be considered.

- **Discount Rate.** Cost-benefit analysis typically expresses costs and benefits that occur over a period of time in terms of their present value, which is calculated using a discount rate. The discount rate reflects the return on foregone present consumption that is sacrificed to secure future consumption. Since foregone present consumption is invested to secure future consumption, analysts often use a discount rate equal to the after-tax real rate of interest or return on capital investment.

Much has been written about the estimation of discount rates for projects with long-term consequences (Lind *et al.*, 1982). For economic analysis of projects in the developing countries, real discount rates between 8 and 12% are commonly used by the World Bank. Each country should select an appropriate discount rate for evaluating the present value of monetary costs and benefits of mitigation options. A study team may wish to conduct sensitivity analyses at a higher and lower rate around the base rate. To evaluate options from the perspective of particular groups (such as households or farmers), analysts should use discount rates that are commonly used in their country for these groups.

In order to assess an option's cost-effectiveness, the discounted costs and benefits are related to its GHG savings or carbon storage. Should the avoided GHG emissions or carbon storage be discounted at the same rate as costs? We suggest that these GHG flows not be discounted. By not discounting them, one assumes that the future economic damage caused by GHG emissions increases at the real rate of discount, which is not unreasonable considering that the potential damage that atmospheric GHG

concentrations might cause in the future is largely unknown. (For a discussion of discounting monetary versus GHG flows, see Sathaye *et al.*, 1993.)

2.7.1 Cost Curves of GHG Mitigation

A GHG-reduction cost curve relates the quantity of GHG which can be reduced by mitigation options to the cost per unit GHG reduction. Correspondingly, a cost curve for stored carbon relates the quantity of stored, or sequestered, carbon to the cost per unit carbon stored. Cost curves for GHG reduction and for carbon storage can be combined to express the relationship between total amount of "avoided" GHG and the cost per unit GHG avoided.

Two distinct forms of cost curves appear in the literature: (a) discrete step curves and (b) continuous curves. These two forms are derived differently and should be interpreted in different ways. Within each of the two forms there are also different methods of construction, different meanings, and different interpretations. Schematic versions of the two forms are shown in Figures 2-2 and 2-3. The blocks in Figure 2-2 correspond to individual mitigation options or "baskets" of options, with widths representing the potential GHG reduction (or carbon stored) and heights representing the cost per unit GHG reduction. The points on the continuous curve (Figure 2-3) represent the increase in total system costs for a given scenario. The costs and the emission reductions represented by each point normally result from the contribution of a mix of several options, as opposed to the discrete step curve in which each option is analyzed separately. Continuous curves can be used to represent the aggregate output from models of the costs of reducing emissions by a given amount.

The aim of a cost curve is ideally to show the relationship between costs and GHG reduction (or carbon stored) over a wide range where both small GHG emission reductions and large reductions are measured. Thus, a cost curve must by its nature be an aggregate of many different technical and structural changes in the energy system. The problems inherent in describing this by one single curve are discussed in more detail in Chapter 3.

When investigating the specific cost of mitigation, i.e., cost per tonne of GHG reduced, it is important to distinguish between average, incremental, and marginal cost. The average cost of GHG reduction reflects the difference in total energy system costs when a specific mitigation scenario is compared to the baseline, divided by the difference in emissions between the two scenarios. The incremental cost can be defined as the increase in costs per unit of emission reduction when a specific mitigation scenario is compared to the previous scenario on the cost curve (rather than the baseline, as in the case for average costs). Thus incremental costs show how expensive each additional step becomes per unit of extra GHG reduced (see Figure 2.4). The marginal cost of GHG abatement is the cost of not emitting the last unit of GHG from the system, or the cost of the last unit of carbon sequestered. In an optimization model, this unit is by definition the most expensive one. The marginal cost will in this case be equal to the shadow price of the imposed emission constraint (if any), or if a carbon tax is introduced in the model, the marginal cost is equal to the tax level.

The disadvantage of only presenting average costs is that increasing costs associated with increasing emission reduction levels are leveled out (see Figure 2.4). An incremental cost curve gives a better picture of the cost consequences of each additional step of measures. Assuming that the average cost curve is increasing and convex, the incremental costs will always be equal to or higher than average costs. The marginal cost curve will then in turn always be equal to or higher than the incremental cost curve. The more model runs (mitigation scenarios) that are used to construct the incremental cost curve, the closer it will reflect the marginal cost curve. In non-optimization models, the marginal costs are not directly calculated. However, by carefully selecting mitigation scenarios when establishing the incremental cost curve, this can be used as approximation of the marginal costs.

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Another issue to consider when establishing cost curves is the representation of time dependence in the costing of mitigation options. Dynamic models include linkage between time periods over the time horizon considered, and thus allow for studying the development over time of different variables, and also allow for a time-dependent description of technologies. In a dynamic model, the choice of mitigation options in one year (or time period) will depend on the choices made in previous years.² Static models only give a "snapshot" representation of the costs, with no time dependency included.

When interpreting cost curves it is important to be aware of what the costs presented include. Cost curves derived from bottom-up models address direct technological costs but typically ignore non-technical market factors and cost impacts of structural changes. Hence, the costs calculated in these models do not reflect GDP losses, as is the case with macro-economic models. The use of cost curves in energy-sector analysis is further discussed in Chapter 3.

Figure 2-2 here

² This is true for models with "myopic foresight". In models with "perfect foresight", the choice of mitigation options is done simultaneously for all time periods assuming that the information given to the model about both previous and future time periods is known at each time step.

Figure 2-3

(full page for the two figures together)

Figure 2-4

2.7.2 Accounting for Mitigation of Non-CO₂ Greenhouse Gases

Expressing the benefit of reducing emissions of different GHGs in a common unit is problematic since the effectiveness of greenhouse gases in trapping the earth's heat varies. Research on this topic has led to the development of the concept of a "global warming potential," or GWP. The GWP is intended to demonstrate the relative impacts on global warming of various gases compared with CO₂. The research conducted to date has established that the effects of various gases are too complex to permit them to be summarized in a single number. The indirect effects of some gases have proven impossible to summarize in terms of GWPs, while the direct effect depends on the time horizon considered (since gases have different lifetimes in the atmosphere). The currently available numerical estimates of GWP relative to CO₂ are given in Table 2-3 for the most important gases.

From a practical standpoint, the main issue is how to compare measures that affect methane with those that affect CO₂ and how to aggregate emissions among GHGs. One option is to present the GWP of methane mitigation options in terms of a range of estimated GWPs. For example, if the chosen range for the methane GWP was 19-110, then the CO₂-equivalent magnitude of GHG reduction for a measure that reduced methane emissions by 100,000 tonnes would be 1.9-11 million tonnes.

**Table 2-3. Numerical Estimates of Global Warming Potential
Relative to Carbon Dioxide**

Greenhouse Gas (GHG)	Direct Effect for Time Horizons of	
	20 Years	100 Years
Carbon dioxide (CO ₂)	1	1
Methane	56-110	19-43
Nitrous oxide (NO _x)	290	320
CFC-11	5,000	3,900
CFC-12	8,000	8,300
HCFC-22	4,300	1,600
HFC-134a	3,100	1,200

Source: IPCC (1992)

2.8 INTEGRATION OF ENERGY AND NON-ENERGY ASSESSMENTS

Integration of results from assessments of the energy sector and the various non-energy sectors can be a challenging task in conducting a national mitigation assessment. The degree of integration that is desired depends on the goals of a national mitigation strategy and whether policy-makers want a ranking of options across sectors.

The most basic type of integration is to simply describe the GHG impacts, costs, and other effects of particular options as identified in each of the sectoral assessments. This is the approach that has been primarily used in the OECD countries for developing and reporting National Action Plans to address climate change. General impacts on the economy are then often addressed by incorporating the different sectors in a general equilibrium framework.

If a coherent ranking of specific options across sectors is desired, however, it requires careful planning of the overall assessment and development of an analytical framework to integrate results. It also requires close communication among the various analysts before, during, and after each of the sectoral assessments. Each of the sectoral studies should use common assumptions for basic macro-parameters and also have a reasonably consistent philosophy for defining a baseline scenario.

If marginal cost curves for GHG mitigation are available from the sectoral assessments, each sector's curve can in principle be combined into a national marginal cost curve. The marginal cost for achieving a specific GHG emission reduction target can then be estimated from the national curve. One can then identify options in each sector, up to the same marginal cost, that together satisfy the overall reduction target. This would provide a theoretically "least-cost" solution for a particular national reduction target, given the limitations in the analytical methods in establishing the sectoral cost curves.

A final ranking of options across sectors may be done by assembling a range of impacts, costs, and benefits for each option (such as the criteria listed in Table 2-2). Options can be assessed in a consistent fashion using a decision analysis framework that allows for a weighting of various quantitative and qualitative criteria. Such a framework allows policy-makers to define the importance that they attach to particular criteria.

2.9 INTEGRATION WITH EMISSION INVENTORIES AND VULNERABILITY AND ADAPTATION ASSESSMENTS

The analysis of mitigation options should be closely linked to and integrated with the preparation of a GHG emission inventory and any vulnerability and adaptation assessments a country is performing. The mitigation analysis should be structured to take advantage of the information generated by these assessments, particularly the emissions inventory. It may also be beneficial to present the results of the inventory, vulnerability and adaptation, and mitigation assessments in one unified document so that conclusions can be drawn about the most important implications of climate change for a country. This will also allow decision-makers to consider the tradeoffs between implementation of adaptation measures and mitigation measures in designing a country's national strategy.

Some of the obvious points of integration between the inventory, vulnerability and adaptation, and mitigation assessments are presented below.

The results of the emission inventory and vulnerability and adaptation assessment provide useful information on GHG emissions and natural resource conditions that should be reflected in the mitigation baseline scenario. The emission inventories will provide a current estimate of GHG emissions, an accounting procedure, and a format that can be helpful in preparing emission projections for future years. The vulnerability assessment will identify likely changes in agricultural, coastal, water, forests, and other resources in the future that will affect the baseline characteristics of these resources.

The inventory results will identify the sectors and sources that have the highest emissions and contributions to global warming or the degree of removal of gases by sinks. This information on the relative current importance of sources and sinks should be considered in determining the scope and emphasis of the mitigation assessment. In addition, the emission factors (and carbon uptake factors) developed and

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used in the inventory should be used in the mitigation assessment in evaluating the emissions or removals associated with different mitigation options. The results of the vulnerability assessment will identify possible changes in natural resource conditions and management practices that could affect the effectiveness of mitigation options. For instance, climate-induced changes in river basin flow may affect hydroelectric potential; changes in forest growth could affect the effectiveness of reforestation programs; and changes in agricultural productivity and production practices may alter strategies for reducing agricultural emissions.

The basic assumptions about population and economic growth and natural resource conditions used in the emission inventory and the vulnerability and adaptation assessment should be consistent with the assumptions used in the mitigation analysis.

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